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A Mark-Recapture Experiment to Estimate the Escapement of Chinook Salmon in the Unuk River, 1999

by

Edgar L. Jones III

and

Scott A. McPherson

August 2000

Alaska Department of Fish and Game Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

Centimeter	cm
Deciliter	dL
Gram	g
Hectare	ha
Kilogram	kg
Kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

Day	d
Degrees Celsius	°C
Degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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Edgar L. Jones III
Division of Sport Fish, Douglas

and

Scott A. McPherson
Division of Sport Fish, Douglas

Alaska Department of Fish and Game
Division of Sport Fish
333 Raspberry Road
Anchorage, AK 99518-1599

August 2000

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Edgar L. Jones III [a]
Alaska Department of Fish and Game, Division of Sport Fish, Region I
P. O. Box 240020, Douglas, AK 99824-0020, USA

Scott A. McPherson
Alaska Department of Fish and Game, Division of Sport Fish, Region I
P. O. Box 240020, Douglas, AK 99824-0020, USA

[a]*Author to whom all correspondence should be addressed: e-mail: ed_jones@fishgame.state.ak.us*

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ABSTRACT

The abundance of medium and large chinook salmon *Oncorhynchus tshawytscha* that returned to spawn in the Unuk River in 1999 was estimated using a two-event mark-recapture experiment. Fish were captured in the lower Unuk River using set gillnets from June through August. Each healthy fish was individually marked with a solid-core spaghetti tag sewn through its back and was given two secondary marks in the form of an upper-left operculum punch and removal of the left axillary appendage. Spawning grounds sampling took place from July through August to recover tags and biological data.

We captured a total of 531 chinook salmon in the lower Unuk River, and 505 of these were marked and released alive. Of the marked and released fish, 380 were large (≥660 mm mideye to tail fork [MEF]), 125 were medium (401–659 mm MEF) and none were small (≤400 mm MEF) in size. On the spawning grounds, 812 fish were sampled; 523 were large fish, and of these, 50 were recaptures that had been previously marked in the lower river with spaghetti tags. We sampled 251 medium fish, and 13 of these were recaptures. Thirty-eight (38) small fish were sampled.

A modified Petersen model was used to estimate that 3,914 (SE = 490, $M = 380$, $C = 523$, $R = 50$) large, 2,267 (SE = 602, $M = 125$, $C = 251$, $R = 13$) medium, and 6,181 (SE = 776) fish >400 mm MEF in length immigrated into the Unuk River in 1999. An estimated 20% of this immigration was sampled during the project. Peak survey counts in August totaled 680 large chinook salmon, about 17% of the mark-recapture estimate of large fish, similar to fractions seen in previous years. Of the spawning population >400 mm MEF, 39% (SE = 4.9%) were age-1.2 fish from the 1995 brood year, 31% (SE = 3.1%) were age-1.3 fish, and 26% (SE = 2.5%) were age-1.4 fish.

Key words: escapement, large and medium chinook salmon, Unuk River, mark-recapture, set gillnet, spaghetti tag, operculum punch, axillary appendage, Petersen model, peak survey counts.

INTRODUCTION

The Unuk, Chickamin, Blossom, and Keta rivers are four of eleven index streams for the chinook salmon *Oncorhynchus tshawytscha* escapement estimation program in Southeast Alaska (Pahlke 1997a). These four systems traverse the Misty Fjords National Monument and flow into Behm Canal, a narrow saltwater passage east of Ketchikan (Figure 1). Peak single-day survey counts of "large" chinook salmon ≥660 mm mid-eye to fork of tail (MEF) are used as indices of escapement in each of these systems. These indices are roughly dome-shaped when plotted against time (since 1975), with peak values occurring between 1987 and 1990 (Pahlke 1997a). Peak 1987–1990 values of escapement are two to five times greater than the "baseline" (1975–1980) or current values of the index.

Several consecutive low survey counts in the early 1990s generated concern by 1992 for the health of the Behm Canal chinook stocks. In response, the Division of Sport Fish of the Alaska Department of Fish and Game (ADF&G) began a research program on the largest chinook salmon producer in Behm Canal, the Unuk River. Goals of the program were to estimate smolt production, escapement, total run size, exploitation rates, harvest distribution, overwinter survival, and marine survival.

The current escapement goal for the Unuk River is 650–1,400 large fish counted in surveys, or about 3,000–7,000 large fish total escapement (McPherson and Carlile 1997). Only large fish are counted in aerial surveys, because they can be distinguished with more confidence from other species that may be present because of their size and color. For our purposes, chinook salmon ≥660 mm MEF are considered large fish and generally consist of fish 3-ocean age or older. Chinook salmon 401–659 mm MEF are considered medium fish, and chinook salmon ≤400 mm MEF are considered small fish. Indices of escapement on the Unuk River are determined each year by summing the peak observer aerial and foot survey counts of large spawners observed in six tributaries: Cripple, Gene's Lake, Kerr, Clear, and Lake creeks plus the Eulachon River (Pahlke 1997a).

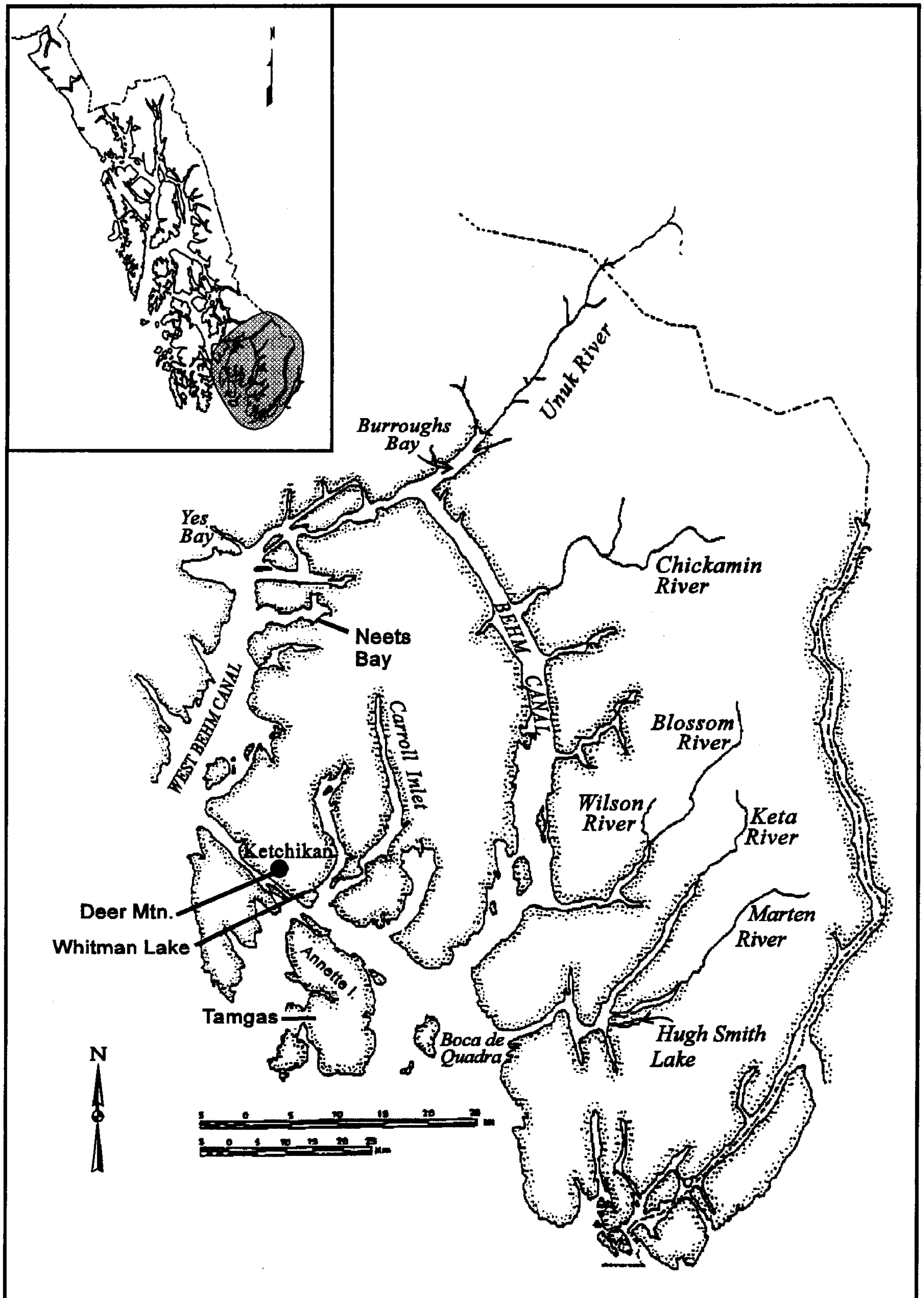

Figure 1.–Behm Canal area in Southeast Alaska and location of major chinook salmon systems and hatcheries.

In an attempt to validate these indices of escapement and to estimate the fraction counted in the surveys, a radiotelemetry study was conducted in 1994 and mark-recapture experiments were conducted in 1994, 1997, and 1998 (Pahlke et al. 1996; Jones et al. 1998; Jones and McPherson 1999). The radiotelemetry study indicated that 83% (SE = 9%) of all spawning occurred in the six tributaries surveyed. The mark-recapture experiments in 1994, 1997, and 1998 estimated that 4,623, 2,970, and 4,132 large chinook salmon entered the river in each of these years. Survey counts of 711, 636, and 840 represented 15%, 21%, and 20% of these estimates. The highest survey count on record occurred in 1986 and was 2,126 large fish (Pahlke 1997a). Average peak survey counts in the six index tributaries of the Unuk River from 1977–1999 are distributed as follows: Cripple Creek (424 fish, 39%), Gene's Lake Creek (325 fish, 30%), Eulachon River (180 fish, 17%), Clear Creek (95 fish, 9%), Lake Creek (25 fish, 2%), and Kerr Creek (37 fish, 3%). Cripple Creek and Gene's Lake Creek are not surveyed from the air because of heavy canopy cover; survey counts in these areas are made on foot. All other index areas are surveyed by helicopter or on foot (Pahlke et al. 1996).

Other studies on the Unuk River were based on coded wire tags (CWTs) inserted in chinook salmon juveniles of the 1982–1986 broods (Pahlke 1995). Indications from this research were that commercial and sport harvest rates on the Unuk River chinook salmon stock (age-1.1–1.5) ranged between 14% and 24%; however, the precision of the harvest estimates was low, and escapement was inferred from the 1994 mark-recapture study expansion of 15% and an alternative expansion of 25% of spawners counted.

Beginning in 1993, chinook salmon fall fingerlings, or young-of-the-year (YOY), and spring smolt were tagged with CWTs on the Unuk River. Fall YOY tagging efforts were 13,789 in 1993, 18,826 in 1994, 40,206 in 1995, 39,177 in 1996, 61,905 in 1997, 33,888 in 1998, and 16,661 in 1999. Spring smolt tagging efforts were 2,642 in 1994, 3,227 in 1995, 7,456 in 1996, 12,517 in 1997, 17,121 in 1998, and 7,948 in 1999 (Appendix A1). The first returns of large fish from this effort (age-1.3 fish from the 1992 brood year) returned in 1997.

The current stock assessment program for adult chinook salmon returning to the Unuk River has three primary goals: (1) to estimate escapement; (2) to estimate age, sex, and length distribution in the escapement; and (3) to sample escapement for the fraction of fish possessing CWTs by brood year. The results are essential to estimate the marked fraction of each brood for CWTd fish and to estimate harvest of this stock in current and future sport and commercial fisheries, and smolt abundance. These harvest and escapement data will enable us to estimate total run size, exploitation rates, harvest distribution, and marine survival for this important chinook salmon indicator stock in southern Southeast Alaska.

STUDY AREA

The Unuk River originates in a heavily glaciated area of northern British Columbia and flows for 129 km where it empties into Burroughs Bay, 85 km northeast of Ketchikan, Alaska. The Unuk River drainage encompasses an area of approximately 3,885 km^2 (Pahlke et al. 1996). The lower 39 km of the Unuk River are in Alaska (Figure 2), and in most years, the Unuk River is the fourth or fifth largest producer of king salmon in Southeast Alaska. Fish trapping efforts in the CWT project indicate that the majority of chinook salmon rear in the U.S. portion of the river.

METHODS

A two-event mark-recapture experiment for a closed population was used to estimate the number of immigrant medium and large chinook salmon to the Unuk River in 1999. Fish were captured using set gillnets in the lower river for the first event and were sampled for marks with a variety of gear types on the spawning grounds for the second event.

EVENT 1: SAMPLING IN THE LOWER RIVER

Adult chinook salmon were captured using set gillnets as they immigrated into the lower Unuk River between 27 June and 26 August 1999. The set gillnets were 37 m (120 ft) long by 4 m (14 ft) deep with 18 cm (7.25 in) stretch mesh. One site was used exclusively for set gillnet fishing in 1999. This site (SN1) is located about 2 miles

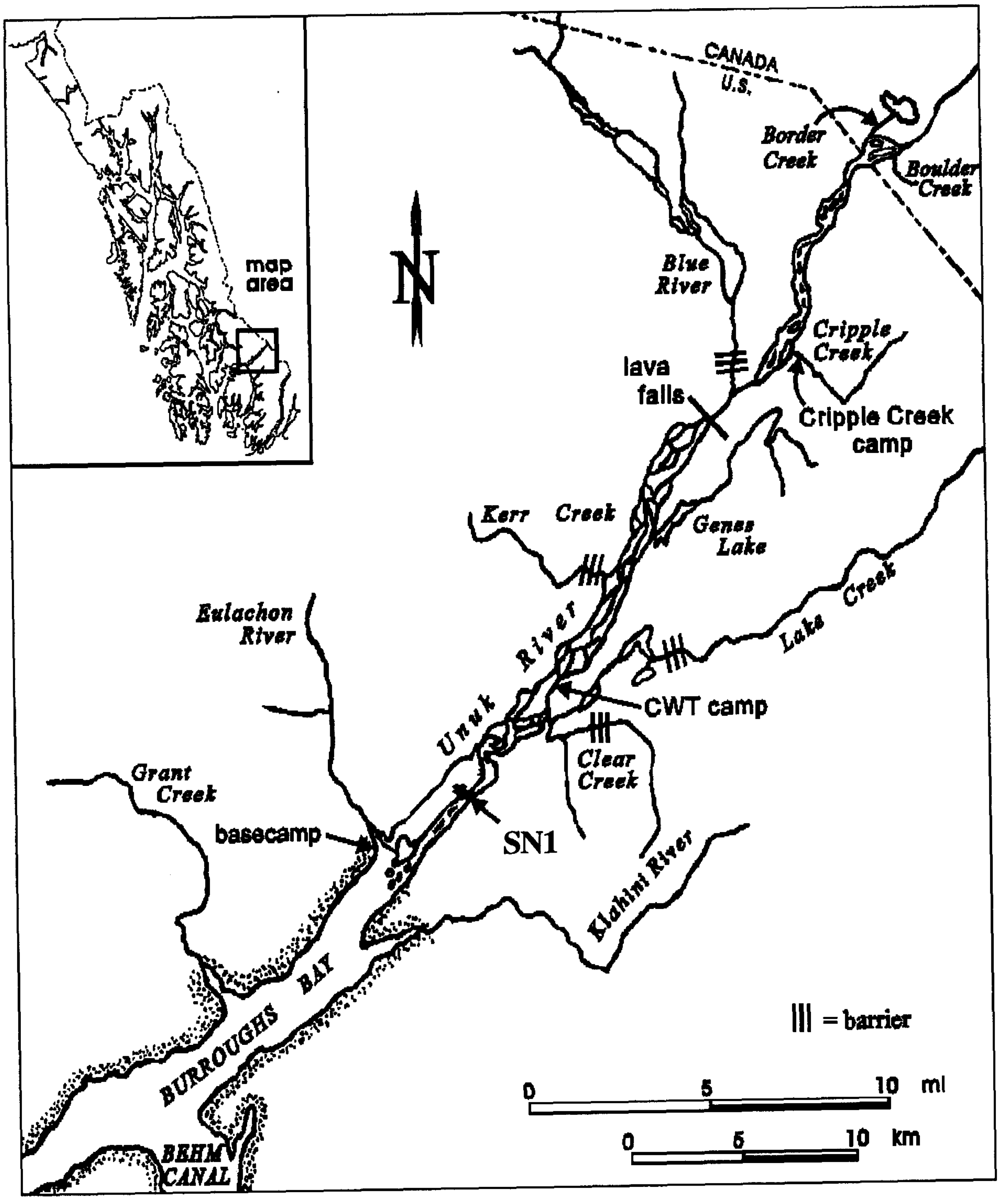

Figure 2.–Unuk River area in Southeast Alaska, showing major tributaries, barriers to chinook salmon migration, and location of ADF&G research sites. Dog Salmon Creek (not shown) flows into the Unuk River about 2 miles upstream of Gene's Lake on the opposite shore.

upstream on the south channel or mainstem of the lower Unuk River well below all known spawning areas, with the exception of the Eulachon River (Figure 3).

Using two back-to-back shifts of personnel, two set gillnets were fished at SN1 (Figure 4) 12 hours per day, six days per week. One net (essentially a cross net) was attached to the shore and ran directly across a small slough to a fixed buoy placed just downstream of a small island (perpendicular to the main flow of the Unuk River). Another net (essentially a lead net) was then attached to the same fixed buoy and trailed downstream along the eddy line formed between the Unuk River mainstem and the side slough.

All fish captured, regardless of health, were sampled for age, sex, and length (ASL) prior to release. Length in MEF was measured to the nearest 5 mm, and sex was estimated from secondary maturation characteristics. Four scales were taken about 1" apart from the preferred area on the left side of the fish. The preferred area is two to three rows above the lateral line and between the posterior terminus of the dorsal fin and the anterior margin of the anal fin (Welander 1940). Scales were mounted on gum cards which held scales from ten fish, as described in ADF&G (1993). The age of each fish was later determined from the pattern of circuli (Olsen 1995), seen on images of scales impressed into acetate cards magnified 70× (Clutter and Whitesel 1956). The presence or absence of an adipose fin was also noted for each sampled fish. Those fish missing adipose fins were sacrificed, and their heads were sent to the ADF&G Tag and Otolith Lab for detection and decoding of CWTs.

All captured fish judged healthy and possessing adipose fins were given three different marks: a uniquely numbered solid-core spaghetti tag, a clip of the left axillary appendage (LAA), and a left upper operculum punch (LUOP) 0.63 cm (¼") in diameter then released. The two finclips enable the detection of primary tag loss. The spaghetti tag consisted of a 5.71 cm (2¼") section of laminated Floy tubing shrunk onto a 38 cm (15") piece of 80-lb test monofilament fishing line. The monofilament was sewn through the back just behind the dorsal fin and secured by crimping both ends of the monofilament in a line crimp. The excess monofilament was then trimmed off. Each spaghetti tag was individually numbered and stamped with an ADF&G phone number.

Event 2: Sampling on the Spawning Grounds

Chinook salmon of all sizes were sampled on Boundary, Chum, Clear, Kerr, and Lake creeks, the Eulachon River, and the Unuk River Mainstem in 1999 (Figure 2). Various methods were used to capture these fish, including rod and reel, spear, dip net, set gillnet, and random carcass pickups. Use of a variety of gear types has been shown to produce unbiased estimates of age, sex, and length composition (McPherson et al. 1997; Jones et al. 1998; Jones and McPherson 1999). All inspected fish were given a left lower operculum punch (LLOP) the first time they were sampled to prevent double sampling. These fish were closely examined for the presence of the primary tag, the LUOP, the LLOP, and the LAA, for a missing adipose fin, and were sampled for ASL data using the same techniques employed in the lower river. Foot survey counts were also performed on each of the sampled tributaries on at least one occasion. Multiple counts were spaced approximately one week apart and coincided with the historical peak observed abundance.

Abundance by Size

Abundance of medium (401–659 mm MEF) and large (≥660 mm MEF) fish was estimated separately, using Chapman's modification of the Petersen estimate (Seber 1982). Estimated abundance ($\hat{N}_i$) for each group was calculated

$$\hat{N}_i = \frac{(M_i + 1)(C_i + 1)}{(R_i + 1)} - 1 \qquad (1)$$

where M_i is the number of fish of size i sampled and marked during event 1, C_i is the number of fish of size i inspected for marks during event 2, and R_i is the number of C_i that possessed unique marks applied during event 1. The general assumptions that must hold for $\hat{N}_i$ to be a suitable estimate of abundance are in Seber

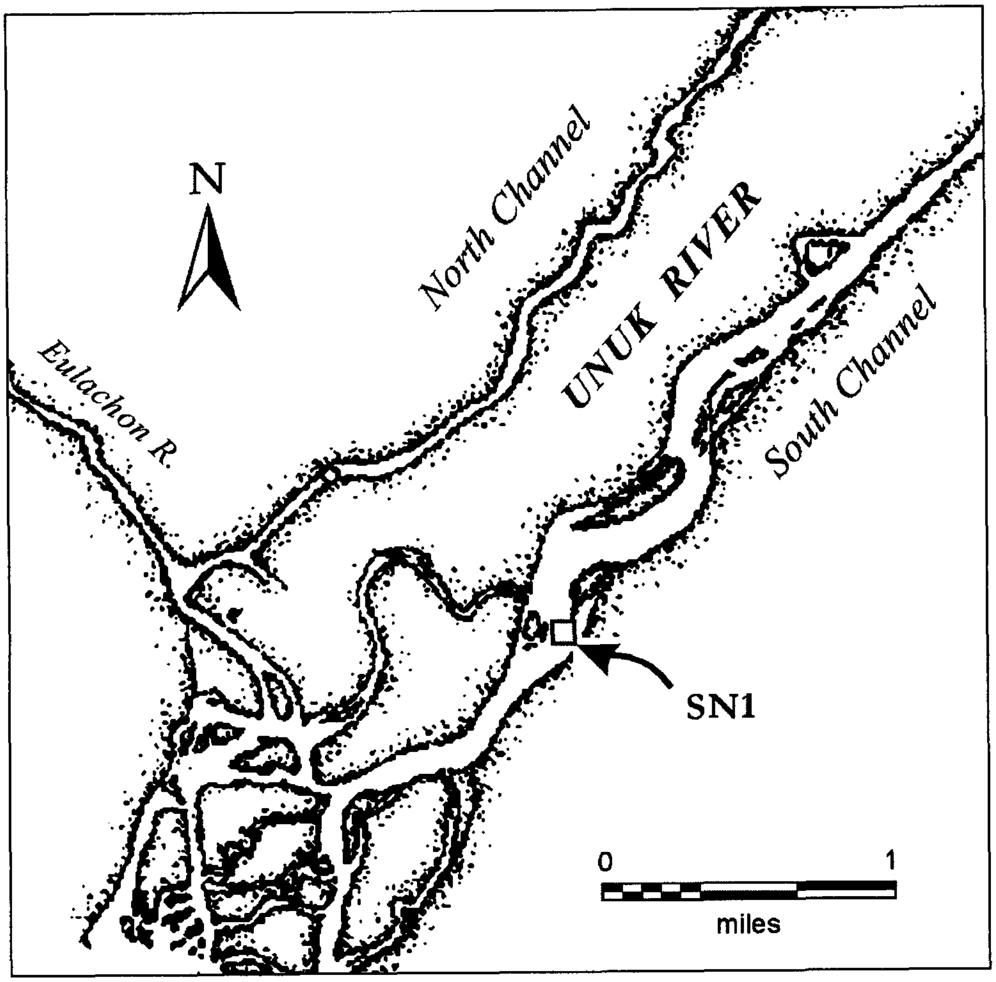

Figure 3.–Location of the set gillnet site (SN1) on the lower Unuk River in 1999.

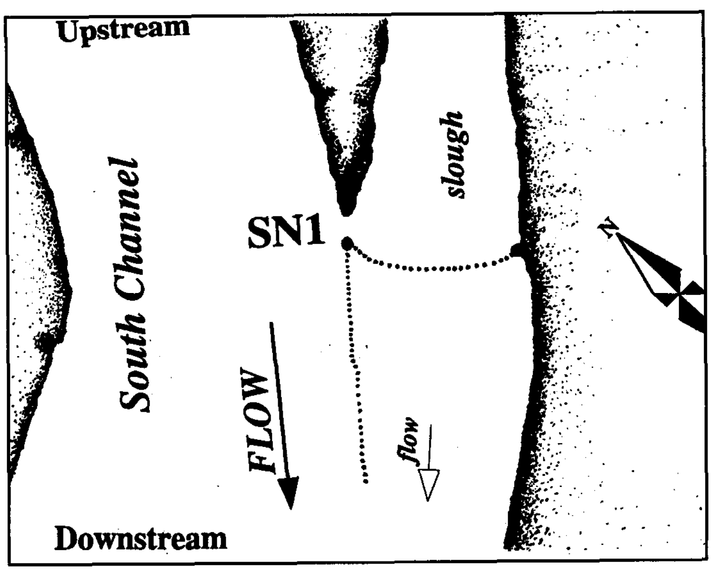

Figure 4.–Detailed drawing of the net placement used at the set gillnet site (SN1) on the lower Unuk River in 1999.

(1982) and may be cast as follows:

- *(a)* every fish has an equal probability of being marked in event 1, or every fish has an equal probability of being captured in event 2, or marked fish mix completely with unmarked fish;
- *(b)* both recruitment and death (emigration) do not occur between sampling events;
- *(c)* marking does not affect the catchability of an animal;
- *(d)* animals do not lose their marks in the time between the two events;
- *(e)* all marks are reported on recovery in event 2; and
- *(f)* double sampling does not occur.

To provide evidence that assumption *a* was met, two chi-square tests were performed: (1) for equal proportions of marks by capture area in event 2; and (2) equal probabilities of recapture in event 2 independent of the stratum of origin. If the null hypothesis of either test was accepted, the pooled Petersen estimator (equation 1) was or would be used to model the mark-recapture data; otherwise a temporally or spatially stratified estimator would be employed. Tests were made separately using the SPAS software program (Arnason et al. 1996).

The possibility of size and sex selective sampling was also investigated, because assumption *a* can also be violated in this manner. The hypothesis that fish of different sizes were captured with equal probability was tested using two Kolmogorov-Smirnov (K-S) 2-sample tests (α = 0.1). These hypotheses tests and adjustments or bias are described in Appendix A2. Because sampling in the lower river spanned the entire known immigration of fish into the Unuk River and continued without interruption, the experiment is, due to the life history of salmon, closed to recruitment (assumption *b*). We were not able to test assumption *c*; however, we were careful to not harm or stress fish and we did not mark obviously injured fish. Radiotelemetry studies in 1994 and 1996 have shown that chinook salmon survive and spawn using this type of capture method (Pahlke et al. 1996; Pahlke 1997b). The effect of tag loss (assumption *d*) is virtually eliminated by using the two secondary marks, and all fish captured during event 2 were inspected for marks (assumption *e*). Double sampling (assumption *f*) of fish was avoided by marking all sampled fish during event 2 with a LLOP.

Variance, bias, and confidence intervals for $\hat{N}_i$ were estimated with modifications of bootstrap procedures in Buckland and Garthwaite (1991). Fish were divided into four capture histories (Table 1). A bootstrap sample was built by drawing with replacement a sample of size $\hat{N}_i$ from the empirical distribution defined by the capture histories. A new set of statistics from each bootstrap sample $\{\hat{M}_i^*, \hat{C}_i^*, \hat{R}_i^*\}$ was generated, along with a new estimate for abundance $\hat{N}_i^*$, and 1,000 such bootstrap samples were drawn creating the empirical distribution $F(\hat{N}_i^*)$, which is an estimate of $F(\hat{N}_i)$.

Table 1.–Capture histories for medium and large chinook salmon in the population spawning in the Unuk River in 1999 (notation explained in text).

Capture history	Medium	Large	Source of statistics
Marked and not sampled in tributaries	112	330	$\hat{M}_i - R_i$
Marked and recaptured in tributaries	13	50	R_i
Not marked, but captured in tributaries	238	473	$C_i - R_i$
Not marked and not sampled in tributaries	1,904	3,061	$\hat{N}_i - \hat{M}_i - C_i + R_i$
Effective population for simulations	2,267	3,914	$\hat{N}_i^+$

The difference between the average $\hat{N}_i^*$ of bootstrap estimates and $\hat{N}_i$ is an estimate of statistical bias in the latter statistic (Efron and Tibshirani 1993, Section 10.2). Confidence intervals were estimated from $\hat{F}(\hat{N}_i^*)$ with the percentile method (Efron and Tibshirani 1993, Section 13.3).

Variance was estimated as

$$\text{var}(\hat{N}_i^*) = (B-1)^{-1}\sum_{b=1}^{B}(\hat{N}_{i(b)}^* - \overline{\hat{N}}_i^*)^2 \qquad (2)$$

where B is the number of bootstrap samples.

Age and Sex Composition

The proportion of the spawning population composed of a given age within medium or large fish was estimated as a binomial variable from fish sampled on the spawning grounds:

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i} \qquad (3)$$

Where $\hat{p}_{ij}$ is the estimated proportion of the population of age j in sized group i, n_{ij} is the number of chinook salmon of age j of size group i, and n_i is the number of chinook salmon in the sample n of size group i taken on the spawning grounds.

Information gathered during event 1 was not used to estimate age or sex composition as tests showed sampling was biased towards catching large fish and sexing fish was difficult using the lower river set gillnets. Samples gathered at each spawning grounds tributary were pooled together because sampling on the spawning grounds was not size-selective within a size group. Sample variance was calculated as:

$$v(\hat{p}_{ij}) = \frac{\hat{p}_{ij}(1-\hat{p}_{ij})}{n_i - 1} \qquad (4)$$

Numbers of spawning fish by age were estimated as the summation of products of estimated age composition and estimated abundance within a size category:

$$\hat{N}_j = \sum_i (\hat{p}_{ij}\hat{N}_i) \qquad (5)$$

with a sample variance calculated according to procedures in Goodman (1960):

$$v(\hat{N}_j) = \sum_i \begin{pmatrix} v(\hat{p}_{ij})\hat{N}_i^2 + v(\hat{N}_i)\hat{p}_{ij}^2 \\ -v(\hat{p}_{ij})v(\hat{N}_i) \end{pmatrix} \qquad (6)$$

The proportion of the spawning population >400 mm MEF composed of a given age was estimated as the summed totals across size categories:

$$\hat{p}_j = \frac{\hat{N}_j}{\hat{N}} \qquad (7)$$

with a variance approximated according to procedures in Seber (1982, p. 8-9):

$$v(\hat{p}_j) = \frac{\sum_i (v(\hat{p}_{ij})\hat{N}_i^2 + v(\hat{N}_i)(\hat{p}_{ij} - \hat{p}_j)^2)}{\hat{N}^2} \qquad (8)$$

Sex composition and age-sex composition for the entire spawning population and its associated variances were also estimated with the equations above by first redefining the binomial variables in samples to produce estimated proportions by sex $\hat{p}_k$, where k denotes gender (male or female), such that $\sum_k \hat{p}_k = 1$, and by age-sex $\hat{p}_{jk}$, such that $\sum_{jk} \hat{p}_{jk} = 1$.

RESULTS

Tagging, Recovery and Abundance

Of 531 chinook salmon sampled in the lower river, 505 were tagged and released (Table 2). Ninety-five percent (95%) of the catches occurred between 29 June and 31 July. Six fish were considered unhealthy upon capture and were not tagged. Of the 505 fish tagged, none were small, 125 were medium, and 380 were large. Forty-nine (49) fish sampled using gillnets were missing adipose fins and 22 of these were sacrificed. Of the total missing adipose fins and

Table 2.–Numbers of chinook salmon marked in the lower Unuk River and inspected for marks on the spawning grounds of the Unuk River in 1999 by size group.

	Length (MEF)			
	0–400 mm	401–659 mm	≥660 mm	Total
A. Released in event 1 with marks (*M*)	0	**125**	**380**	505
B. Inspected at:				
1. Cripple Creek				
Inspected (C)	17	**132**	**250**	399
Recaptured (R)	0	**9**	**20**	29
Recaptured/captured	0	**0.064**	**0.074**	0.068
2. Gene's Lake Creek				
Inspected (C)	16	**57**	**115**	188
Recaptured (R)	0	**1**	**10**	11
Recaptured/captured	0	**0.017**	**0.080**	0.055
3. All others[a]				
Inspected (C)	5	**62**	**158**	225
Recaptured (R)	0	**3**	**20**	23
Recaptured/captured	0	**0.046**	**0.112**	0.093
Total inspected				
Inspected (C)	38	**251**	**523**	812
Recaptured (R)	0	**13**	**50**	63
Recaptured/captured	0	**0.049**	**0.087**	0.072

[a] Includes Boundary, Chum, Clear, Kerr, and Lake creeks, the Eulachon River, and the Unuk River mainstem, combined.

of those sacrificed, 78% and 95% were males, respectively. In general, the numbers of recaptures sampled on the spawning grounds in each tributary and the dates when they were first marked exhibited some features of the numbers seen in the daily gillnet catches (Figure 5).

The length distributions of marked medium, large, and medium and large fish combined were not significantly different than length distributions for fish *recaptured* on the spawning grounds ($P = 0.23$, $P = 0.99$, and $P = 0.85$; Figure 6). Thus, sampling on the spawning grounds was not size selective and the mark-recapture data did not need length stratification. However, the experiment was stratified by size because we desired $\hat{N}_{lg}$ for comparison with the aerial survey counts.

In contrast, while length distributions of marked chinook salmon were comparable to those fish *inspected* on the spawning grounds for large fish ($P = 0.07$), they were not for medium ($P < 0.001$) and medium and large fish combined ($P < 0.001$; Figure 7). Also, the fractions of medium and large chinook salmon with marks were significantly different ($P = 0.05$), suggesting that it was more likely to catch a large fish in the lower river set gillnets versus a medium fish.

Tests to determine if temporal or spatial stratification were needed were conducted by stratifying the mark-recapture data by three time and recovery periods as follows:

Time	Marks	Cripple Creek	Gene's Lake Creek	All others[a]
Medium chinook salmon				
Stratum 1	31	1		
Stratum 2	33	3		1
Stratum 3	61	5	1	2
U_i[b]		123	56	59
Large chinook salmon				
Stratum 1	154	7	4	10
Stratum 2	95	9	3	7
Stratum 3	131	4	3	3
U_i[b]		230	105	138

[a] Includes Boundary, Chum, Clear, Kerr, and Lake creeks, the Eulachon River, and the Unuk River mainstem, combined.

[b] $U_{i.}$ is the number not marked.

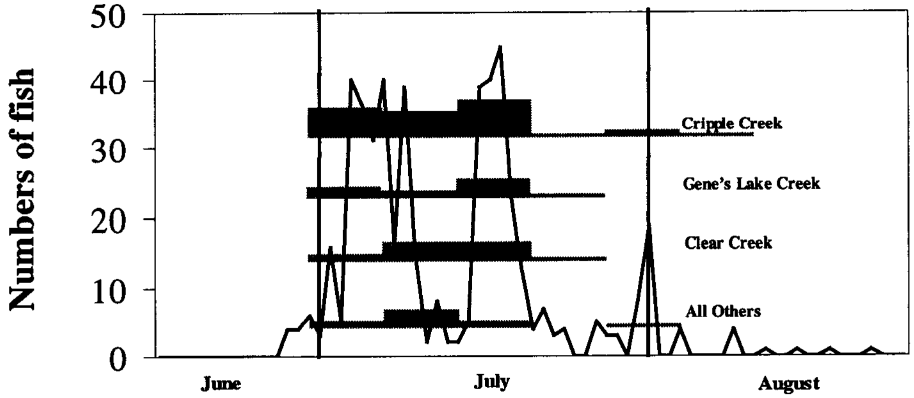

Figure 5.–Weekly numbers of marked chinook salmon sampled in 1999 at eight locations (bar graphs) and associated time of marking, set against the daily set gillnet catches in the lower Unuk River (line graph). X-axis pertains to time of marking; 'All Others' includes Boundary, Chum, Clear, Kerr, and Lake creeks, the Eulachon River, and the Unuk Mainstem, combined.

Probability of tagging was equal among medium fish as demonstrated by equal marked fractions (χ^2 = 2.10, df = 2, P = 0.35) inspected in the various tributaries (Cripple Creek: 0.068; Gene's Lake Creek: 0.018; all others: 0.048). The test for equal proportions of marks from each marking strata suggests equal fractions (χ^2 = 2.30, df = 2, P = 0.32). So the pooled Petersen estimate was acceptable for medium fish. For large fish, equal fractions were marked (χ^2 = 2.56, df = 2, P = 0.28) in the various tributaries (Cripple Creek: 0.08; Gene's Lake Creek: 0.09; all others: 0.13). Thus, sufficient evidence exists for the use of the pooled Petersen estimate for large fish as well. Estimated abundance of medium fish ($\hat{N}_{med}$) on the spawning grounds in 1999 (n_1 = 125, n_2 = 251, m_2 = 13) was 2,267 (SE = 602) (Table 2). Statistical bias of the estimate was small (3.4%) and the 95% confidence interval for the estimated abundance of medium fish is 1,506 to 3,811.

Estimated abundance of large fish ($\hat{N}_{lg}$) on the spawning grounds in 1999 (n_1 = 380, n_2 = 523, m_2 = 50) was 3,914 (SE = 490) (Table 2). Statistical bias of the estimate was negligible (1.5%), and the 95% confidence interval for the estimated abundance of large fish is 3,110 to 5,071. Four (8%) of the recoveries had lost their primary tags. These fish were detected as being previously marked from the presence of the left upper operculum punch (LUOP) and a missing left axillary appendage (LAA). In addition to the 774 medium and large fish sampled on the spawning grounds, 38 small fish were sampled. Five of these fish were missing adipose fins and were subsequently sacrificed.

Estimated abundance of all fish >400 mm MEF ($\hat{N} = \hat{N}_{med} + \hat{N}_{lg}$) for 1999 was 6,181 (SE = 776). Statistical bias of the estimate was small (2.2%) and the 95% confidence interval is 4,770 to 7,592.

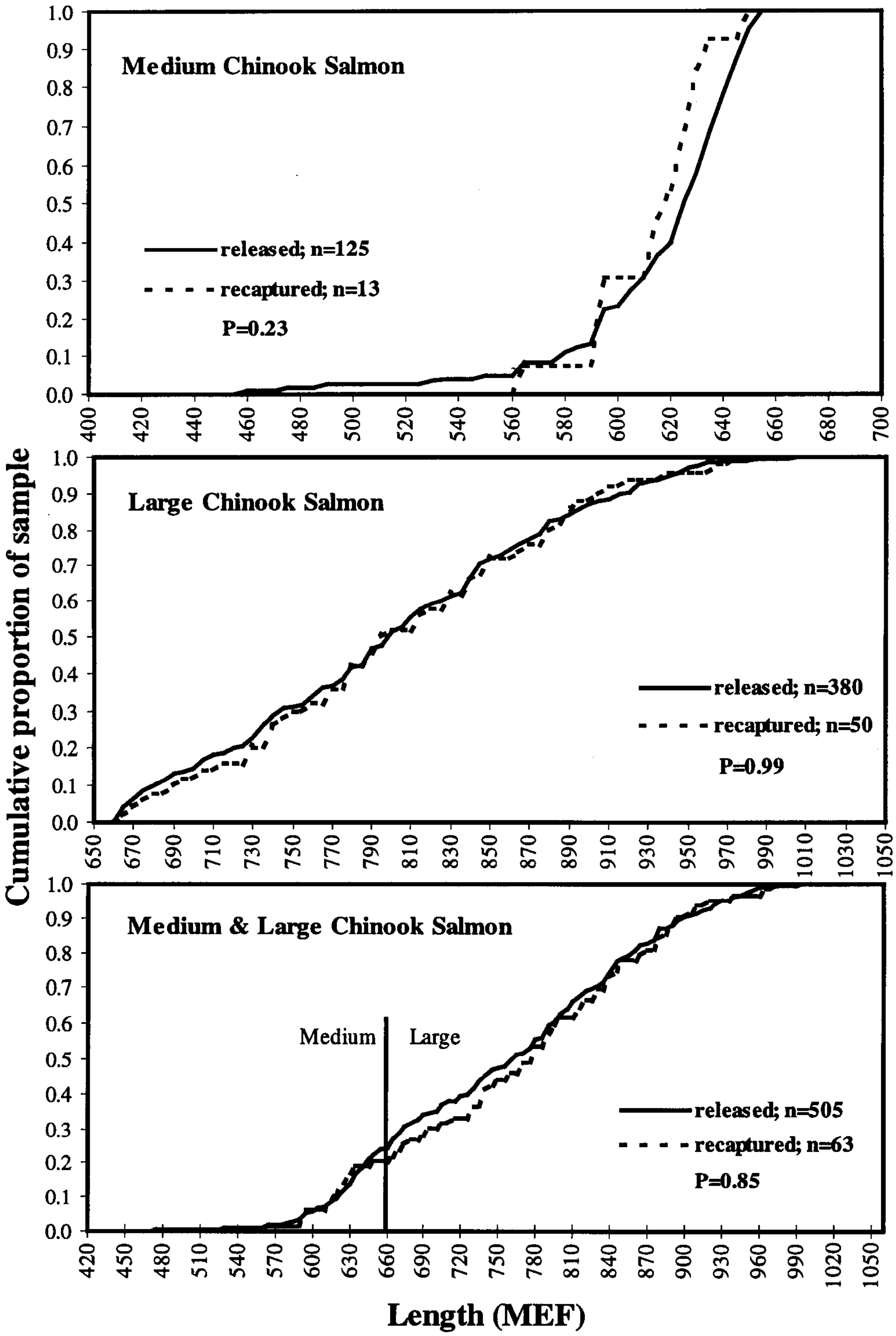

Figure 6.–Cumulative relative frequencies of medium, large, and medium and large chinook salmon (combined) marked in the lower Unuk River in 1999 versus those recaptured on the spawning grounds at eight tributary sampling sites.

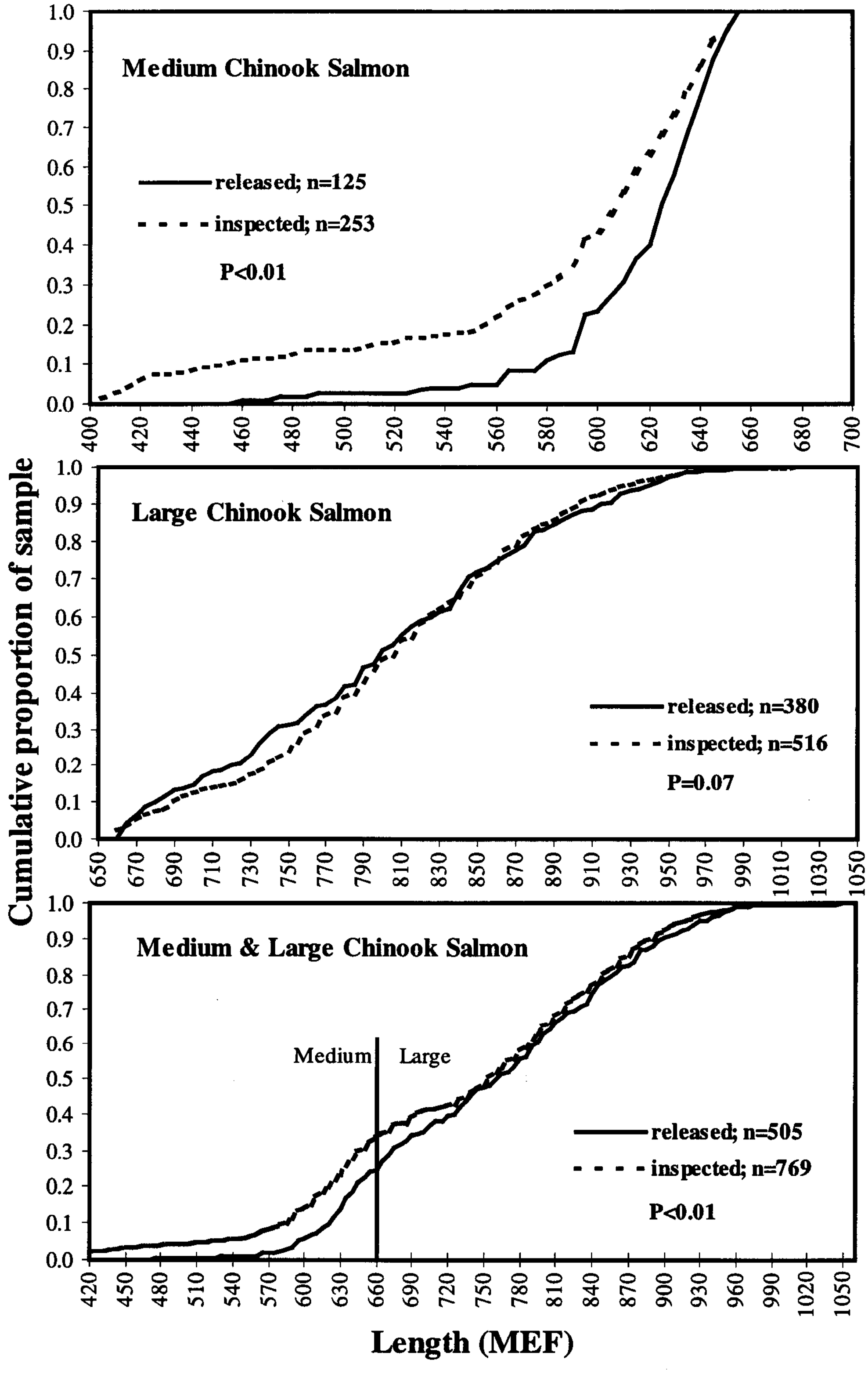

Figure 7.–Cumulative relative frequencies of medium, large, and medium and large chinook salmon (combined) marked in the lower Unuk River in 1999 versus those inspected on the spawning grounds at eight tributary sampling sites.

ESTIMATES OF AGE AND SEX COMPOSITION

Age-1.2, age-1.3 and age-1.4 chinook salmon dominated the age compositions of fish >400 mm MEF (Appendix A3). However, 43% of all fish sampled on the spawning grounds were age-1.1 and age-1.2. Age-1.2 fish were 39% (SE = 4.9%), age-1.3 fish 31% (SE = 3.1%), and age-1.4 fish 26% (SE = 2.5%) of the escapement of medium and large fish; 65% (SE = 3.4%) of these were males (Table 3). Age-1.2 fish constituted 89% (SE = 2.1%) of the medium fish (Figure 8), which with the exception of one fish, were 100% males. Age-1.3 fish accounted for 49% (SE = 2.3%) and age-1.4 fish accounted for 40% (SE = 2.2%) of all large fish in the escapement; males composed 49% (SE = 2.3%) of these fish. There were an estimated 2,008 (SE = 352) spawning females in 1999.

In the gillnet sampling in the lower river, mostly large fish were captured (74%) consisting of 17% age-1.2 fish, 46% age-1.3 fish, and 37% age-1.4 fish (Appendix A3). Among the medium fish sampled, 96% were age-1.2, 3% were age-1.1, and 1% were age-1.3 and age-1.4 fish. Sex compositions of medium and large fish sampled in the lower river (males 69%) were similar as those from the combined spawning grounds samples (males 65%). Table 4 and Figure 8 show lengths by age of all fish sampled for length and successfully aged on the spawning grounds. Length compositions were similar between samples gathered in the lower river and on the spawning grounds within sex and by age class.

DISCUSSION

At the inception of this study in 1994 we were concerned that fish bound for the various spawning tributaries might be unevenly distributed across lower river entry channels and that fish bound for some areas (i.e., Eulachon River) may be disproportionately sampled. In the 1994 study, two set gillnet sampling sites were used to capture and mark fish. Radiotelemetry and spaghetti tag recoveries from that study showed that fish bound for the various spawning tributaries were tagged in nearly equal proportions at two different set gillnet sites (Pahlke et al. 1996). In the 1997 and 1998 studies only one set gillnet site was used to capture fish (Jones et al. 1998, Jones and McPherson 1999). It was evident from these studies that fish bound for the various spawning tributaries, including the Eulachon River, were tagged in nearly equal proportions using this one site. Therefore, this year we again used only one sampling site, that was located on the mainstem of the lower Unuk River.

Some fish displayed a "sulking" behavior or a delay in upstream migration (Pahlke et al. 1996) and such behavior was likely present in this year's study as well. This backing-down phenomenon of tagged chinook salmon has been observed in other studies (Milligan et al. 1984; Johnson et al. 1992; Johnson 1993; Bendock and Alexandersdottir 1993; Eiler et al. *In prep*). In the 1994 study, 86% of radio tagged fish were successfully tracked to a spawning tributary. We feel confident that marked and unmarked fish died at the same rate and that the estimated abundance is therefore unbiased (Seber 1982). Loss of primary tags was not a problem in this study as only two large females and two medium males were captured missing the primary tag. In all cases, secondary tags were clearly visible on recaptured fish, once in hand.

The success of this mark-recapture experiment rests largely on the assumptions that fish were marked in proportion to their passing abundance, or that every fish had an equal chance of being inspected. The statistical tests performed suggest that medium and large fish were marked in proportion to their abundance and that medium fish marked at different times were captured with equal probabilities at different recovery locations. Thus, our estimates of abundance pertain to all medium and large chinook salmon spawning in the Unuk River and are unbiased.

As was the case in 1997 and 1998, use of gillnets in the lower river appeared to be selective toward bigger medium fish yet almost all sizes of large fish were captured. Age-1.1 fish captured on the spawning grounds were on average 363 mm MEF in 1997, 433 mm MEF in 1998, and 434 mm MEF in 1999. Obviously, age-1.1 fish were on average

Table 3.–Age and sex composition of medium (401–659 mm MEF) and large (≥660 mm MEF) chinook salmon escapement in the Unuk River in 1999, determined using data gathered from the spawning grounds.

		BROOD YEAR AND AGE CLASS					
		1996	1995	1994	1993	1992	
		1.1	1.2	1.3	1.4	1.5	Total
PANEL A. AGE COMPOSITION OF MEDIUM CHINOOK SALMON							
Males	n	24	201	1			226
	%	10.6	88.9	0.4			99.6
	SE of %	2.1	2.1	0.4			0.4
	Escapement	240	2,007	10			2,257
	SE of esc.	78	536	10			600
Females	n				1		1
	%				100.0		0.4
	SE of %				0.0		0.4
	Escapement				10		10
	SE of esc.				10		10
Sexes combined	n	24	201	1	1		227
	%	10.6	88.5	0.4	0.4		100.0
	SE of %	2.0	2.1	0.4	0.4		
	Escapement	240	2,007	10	10		2,267
	SE of esc.	78	535	10	10		602
PANEL B. AGE COMPOSITION OF LARGE CHINOOK SALMON							
Males	n		48	128	56	1	233
	%		20.6	54.9	24.0	0.4	48.9
	SE of %		2.7	3.3	2.8	0.4	2.3
	Escapement		395	1,052	460	8	1,916
	SE of esc.		73	154	81	8	256
Females	n		3	104	135	1	243
	%		1.2	42.8	55.6	0.4	51.1
	SE of %		0.7	3.2	3.2	0.4	2.3
	Escapement		25	855	1,110	8	1,998
	SE of esc.		14	130	161	8	266
Sexes combined	n		51	232	191	2	476
	%		10.7	48.7	40.1	0.4	100.0
	SE of %		1.4	2.3	2.2	0.3	
	Escapement		419	1,907	1,570	16	3,914
	SE of esc.		76	255	215	12	490
PANEL C. AGE COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON.							
Males	%	5.7	57.6	25.5	11.0	0.2	67.5
	SE of %	0.9	3.3	2.6	1.4	0.1	3.7
	Escapement	240	2,402	1,062	460	8	4,173
	SE of esc.	78	538	154	81	8	652
Females	%		1.2	42.6	55.8	0.4	32.5
	SE of %		0.3	4.3	4.4	0.1	3.7
	Escapement		25	855	1,120	8	2,008
	SE of esc.		14	130	161	8	266
Sexes combined	%	3.9	39.3	31.0	25.6	0.3	100.0
	SE of %	1.0	4.9	3.1	2.5	0.1	
	Escapement	240	2,427	1,917	1,580	16	6,181
	SE of esc.	78	538	255	215	12	776

Table 4.–Estimated average length (MEF in mm) by age and sex of chinook salmon sampled on the Unuk River in 1999.

		BROOD YEAR AND AGE CLASS					
		1996	1995	1994	1993	1992	
		1.1	1.2	1.3	1.4	1.5	Total
PANEL A. LENGTH COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON SAMPLED USING GILLNETS IN THE LOWER UNUK RIVER							
Males	n	3	178	99	48		328
	Avg. length	493	640	772	886		715
	SD	28	42	48	54		88
	SE	16	3	5	8		5
Females	n		1	62	82		145
	Avg. length		710	792	876		839
	SD		0	45	56		72
	SE		0	6	6		6
Sexes combined	n	3	179	161	130		473
	Avg. length	493	641	780	880		753
	SD	28	42	48	55		89
	SE	16	3	4	5		4
PANEL B. LENGTH COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON SAMPLED ON THE UNUK RIVER SPAWNING GROUNDS							
Males	n	24	249	129	56	1	459
	Avg. length	434	619	765	878	1105	683
	SD	24	49	50	66	0	99
	SE	5	3	4	9	0	5
Females	n		3	104	136	1	244
	Avg. length		722	793	874	880	838
	SD		13	39	55	0	68
	SE		7	4	5	0	4
Sexes combined	n	24	252	233	192	2	703
	Avg. length	434	620	778	875	993	737
	SD	24	50	48	58	159	184
	SE	5	3	3	4	113	7

much smaller in 1997, versus 1998 and 1999. Consequently during event 1, no age-1.1 fish were sampled in 1997 and five and three fish were sampled in 1998 and 1999, respectively (Table 5).

The dramatic differences among sizes of age-1.1 fish from these three years may correspond to the recent El Nino event. It may be that ocean productivity was greater or that competition for available resources was lower in 1997 and 1998 versus 1996, the first year of ocean growth.

For large fish, very little difference in age and sex composition occurred between gillnet and spawning ground samples (Appendix A3, panels C and D). In addition, there was no significant difference between the length distributions of large fish tagged versus those fish recaptured or inspected (Figures 6 and 7).

Female chinook salmon tend to die on or near their redds whereas males usually drift downstream in a moribund state after spawning (Kissner and Hubartt 1986). Because of this behavior, estimates of age, sex, and size composition for fish sampled in carcass-only surveys tend to be biased towards females, which are also larger fish on average. To help compensate for this we used various sampling techniques such as rod and reel snagging and lure fishing, spear, gillnet, dipnet, and carcass-only surveys during sampling on the spawning grounds. Foot surveys of abundance were used

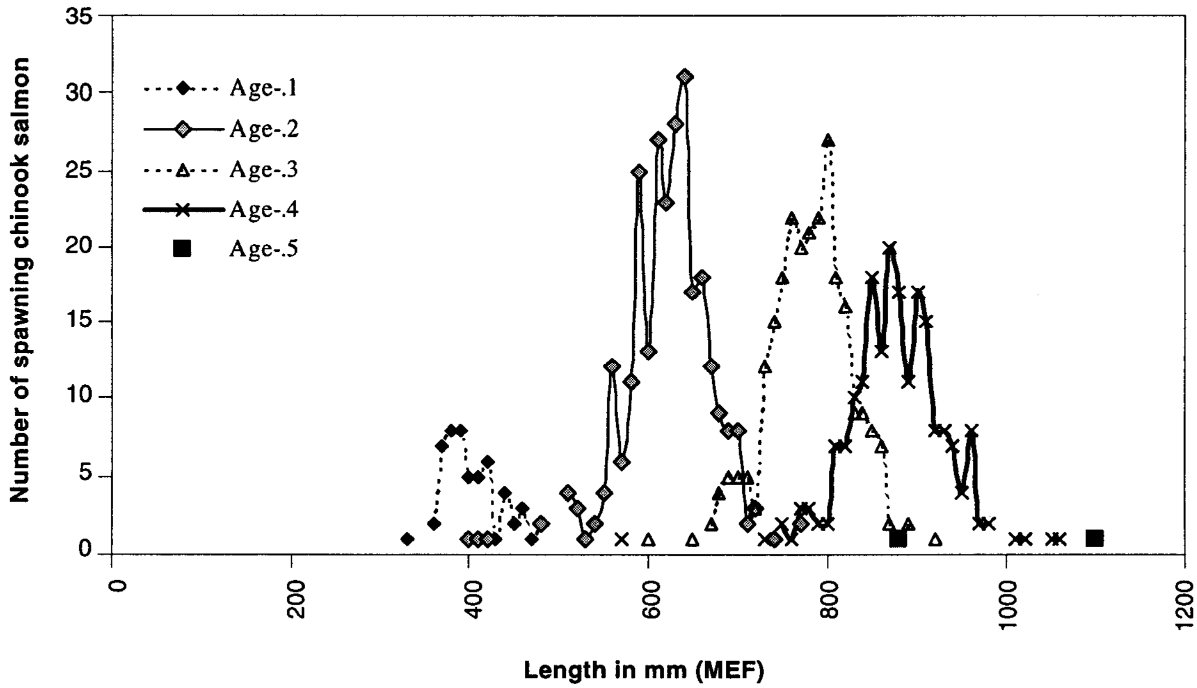

Figure 8.–Numbers of chinook salmon sampled by length and ocean-age at all eight tributary spawning sites on the Unuk River in 1999.

to approximate the amount of effort required to sample the various spawning sites in proportion to abundance. Therefore, in estimating abundance and age and sex composition for the watershed, it was presumed that the combined samples from the various spawning tributaries for medium and large fish were representative of the total population.

The 95% relative precision (RP) of mark-recapture estimates of abundance has been shown to improve in consecutive years of study. On the Chickamin River, RPs of ±61% and ±25% occurred in 1995 and 1996 (Pahlke 1996, 1997b). On the Unuk River, RPs of ±54%, ±17%, and ±20% occurred in 1994, 1997, and 1998. These results suggest that the knowledge gained from previous mark-recapture studies is beneficial and positively influences the success of future studies. This year our goal was to achieve results similar to those obtained during 1997 and 1998 (Jones et al. 1998; Jones and McPherson

Table 5.–Estimated average length (MEF in mm) of age-1.1 chinook salmon sampled by event in the Unuk River in 1997, 1998, and 1999.

	SAMPLE YEAR			
	1997	1998	1999	Average
Event 1 sampling using gillnets in the lower river				
n		5	3	8
Avg. length		447	493	464
SD		20	28	35
SE		9	16	12
Event 2 sampling on the spawning grounds				
n	51	40	24	115
Avg. length	363	433	434	402
SD	39	24	24	52
SE	5	4	5	5

1999), and a 95% RP of ±25% (CV = 13%) was obtained, an excellent level of precision for a detailed stock assessment study.

As was the case in 1994, 1997, and 1998, the estimated abundance of large fish was considerably greater than corresponding estimates obtained from the peak survey counts. Observer bias resulting in underestimation of the actual abundance is a common pattern seen in other studies of chinook salmon in Southeast Alaska and in northern British Columbia (Johnson et al. 1992; Pahlke et al. 1996; McPherson et al. 1997; Jones et al. 1998; Jones and McPherson 1999) and of salmon in general (Jones 1995). This year, about 17% (680) of the estimated 3,914 large fish immigrating to the Unuk River were counted in the peak survey count. This percentage is similar to that of the 1994, 1997, and 1998 studies and the 1995 and 1996 Chickamin River studies (Table 6) (Pahlke 1996, 1997b, Pahlke et al. 1996; Jones et al. 1998; Jones and McPherson 1999).

This ongoing study is designed to estimate the escapement of chinook salmon in the Unuk River and is an integral part of a larger full stock assessment program which estimates the total run size, exploitation rate, harvest distribution, marine survival, and other population parameters for these fish. Fall juvenile and spring chinook salmon smolt have been tagged with CWTs since the fall of 1993 (1992 brood year). Good numbers of these fish returned in 1997, 1998, and 1999 as evidenced by the 50, 127, and 135 (Appendix A4) adipose-clipped fish sampled. Since juvenile and smolt tagging was initiated, attempts have been made to tag greater numbers of fish each year with CWTs (Appendix A1). These efforts have helped to increase the CWT marked fraction from a low of 4% for the 1992 brood to 9%, 10%, 14%, and 11% for the 1993, 1994, 1995, and 1996 broods (Appendix A4).

In recent years, peak survey counts of escapement have been at or below the 20-year average of 1,087 large fish: 711 in 1994, 772 in 1995, 1,167 in 1996, 636 in 1997, 840 in 1998, and 680 in 1999 (Table 6). The escapement goal range, expressed in survey counts, for this stock is 650 to 1,400 large spawners (McPherson and Carlile 1997). The recent survey counts have generally been in the lower half of this range, but our work indicates that returns in the near future may be larger. An estimated 2,427 (SE = 75) age-1.2 (1995 brood year) fish returned to the Unuk River in 1999 (Table 3). This unusually high percentage (39%) and number of fish in the overall escapement was far greater than that seen in 1998 (24%; Jones and McPherson 1999) and 1997 (25%; Jones et al. 1998) and nearly triples the percentage (13%) seen in 1994 (Pahlke et al. 1996). Also, the 1994 brood year produced an estimated 1,917 (SE = 62) age-1.3 fish in 1999. In 2000, age-1.3 and age-1.4 fish will be returning from the 1994 and 1995 brood years, and if the brood year strength seen in 1999 continues, we should expect the 2000 escapement to be larger than that seen in 1999.

CONCLUSIONS AND RECOMMENDATIONS

Because this project will be performed again in 2000, we recommend some strategies for continued success. As in 1997, 1998, and 1999, effort should concentrate on maximizing the numbers of fish tagged during event 1 sampling in the lower river and the numbers of fish sampled for tags at the various spawning tributaries. SN1 will be used in 2000 as the event 1 tagging site since it has produced more than adequate results in 1997, 1998, and 1999. Knowledge of run-timing gathered in 1994, 1997, 1998, and 1999 should be used as an indicator of peak spawning abundance and optimum sampling periods. In 1997, 1998, and 1999, very few fish lost their primary tags, and we feel that this is mainly due to the use of the stronger, more durable 80-lb test monofilament in spaghetti tags and to increased efficiency in their application. Thus, the same primary tag will be used in 2000. The secondary marks used in the past have proven to be a failsafe method for determining tag loss and they will be used in 2000. We recommend that survey counts continue in a similar manner as those made in the past and that observers attempt to maintain consistency in counting efficiency from year to year. Further, we recommend that more effort be applied to the foot survey counts

Table 6.–Peak survey counts compared to mark-recapture estimates of abundance and other statistics for large chinook salmon (≥660 mm MEF) in the Unuk River (1994, 1997, 1998, and 1999) and the Chickamin River (1995 and 1996).

	Chickamin River		Unuk River				
	1995	1996	1994	1997	1998	1999	Average
Survey count	356	422	711	636	840	680	608
Mark-recapture estimate (M-R)	2,309	1,587	4,623	2,970	4,132	3,914	3,256
SE (M-R)	723	199	1,266	271	413	490	560
Survey count/(M-R) (%)	15.4	26.6	15.4	21.4	20.3	17.4	18.7
M-R CV	31%	13%	27%	9%	10%	13%	
95% RP	61%	25%	54%	18%	20%	25%	34%
Expansion Factor (EF)	6.49	3.76	6.50	4.67	4.92	5.76	5.36
SE (EF)	2.0	0.5	1.8	0.4	0.5	0.7	0.9

to increase the probability of performing a count during the period of peak abundance. Finally, the age, sex, and length composition estimates from the 1997, 1998, and 1999 studies have been relatively unbiased which can be primarily attributed to the use of multiple capture gear during spawning grounds sampling. We will continue this practice in future years.

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LITERATURE CITED

ADF&G (Alaska Department of Fish and Game). 1993. Length, sex, and scale sampling procedure for sampling using the ADF&G adult salmon age-length mark-sense form version 3.0. Commercial Fisheries Management and Development Division, Douglas.

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences. 2106:37.

Bendock, T. and M. Alexandersdottir. 1993. Hooking mortality of chinook salmon released in the Kenai River, Alaska. North American Journal of Fisheries Management 13:540-549.

Buckland, S. T. and P. H. Garthwaite. 1991. Quantifying precision of mark-recapture estimates using the bootstrap and related methods. Biometrics 47:255-268.

Clutter R. and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Bulletin of the International Pacific Salmon Fisheries Commission 9, New Westminster, British Columbia.

Efron, B. and R. J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, New York.

Eiler, J., M. M. Masuda, J. Pella, H. R. Carlson, R. F. Bradshaw, and B. D. Nelson. *In prep.* Stock composition, escapement estimate, and timing of chinook salmon returns in the Taku River, Alaska and British Columbia.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

Johnson, R. E. 1993. Chilkat River chinook salmon studies, 1992. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 93-50, Anchorage.

Johnson, R. E., R. P. Marshall, and S. T. Elliott. 1992. Chilkat River chinook salmon studies, 1991. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 92-49, Anchorage.

Jones, E. L. III. 1995. Observer variability and bias in estimation of Southeast Alaska pink salmon escapement. Master's thesis, University of Alaska Fairbanks, Juneau.

Jones, E. L. III. 1999. A mark-recapture experiment to estimate the escapement of chinook salmon in the Unuk River, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-14, Anchorage.

Jones, E. L. III., S. A. McPherson, and D. L. Magnus. 1998. A mark-recapture experiment to estimate the escapement of chinook salmon in the Unuk River, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-23, Anchorage.

Kissner, P. D., Jr. and D. J. Hubartt. 1986. A study of chinook salmon in Southeast Alaska. Alaska Department of Fish and Game, Annual Report 1985-1986, Project F-10-1, 27 (AS-41).

McPherson, S. A. and J. K. Carlile. 1997. Spawner-recruit analysis of Behm Canal chinook salmon stocks. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Regional Information Report 1J97-08, Juneau.

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1997. Spawning abundance of chinook salmon in the Taku River in 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-14, Anchorage.

Milligan, P. A., W. O. Rublee, D. D. Cornett, and R. A. C. Johnston. 1984. The distribution and abundance of chinook salmon in the upper Yukon River basin as determined by a radio-tagging and spaghetti tagging program: 1982–1983. Department of Fisheries and Oceans, Yukon River Basin Study, Technical Report 35. Whitehorse, Yukon Territory.

Olsen, M. A. 1992. Abundance, age, sex and size of chinook salmon catches and escapements in Southeast Alaska in 1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 92-07, Juneau.

Pahlke, K. A. 1995. Coded-wire tagging studies of chinook salmon on the Unuk and Chickamin rivers, 1983-1993. Alaska Department of Fish and Game, Alaska Fishery Research Bulletin Series 2(2):93-113.

Pahlke, K. A. 1996. Abundance of the chinook salmon escapement on the Chickamin River, 1995. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 96-37, Anchorage.

Pahlke, K. A. 1997a. Escapements of chinook salmon in Southeast Alaska and transboundary rivers in 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 97-33, Anchorage.

Pahlke, K. A. 1997b. Abundance and distribution of the chinook salmon escapement on the Chickamin River, 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 97-28, Anchorage.

Pahlke, K. A., S. A. McPherson, and R. P. Marshall. 1996. Chinook salmon research on the Unuk River, 1994. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 96-14, Anchorage.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, second edition. MacMillan and Company, New York.

Welander, A. D. 1940. A study of the development of the scale of the chinook salmon (*Oncorhynchus tshawytscha*). Master's thesis, University of Washington, Seattle.

APPENDIX A

Appendix A1.–Numbers of Unuk River chinook salmon fall fry and spring smolt captured and tagged with coded-wire tags, 1992 brood year to present.

PANEL B. TOTAL NUMBERS OF FALL AND SPRING CHINOOK JUVENILES AND SMOLT TAGGED BY YEAR AND SUMMED BY BROOD YEAR					
Brood year	**Year tagged**	**Fall/ spring**	**Tag code**	**Number tagged**	**Valid tagged**
1992	1993	Fall	043803	10,316	10,263
1992	1993	Fall	043804	441	433
1992	1993	Fall	043805	3,202	3,093
1992	1994	Spring	044206	2,653	2,642
		1992 Brood Year Total			**16,431**
1993	1994	Fall	043349	1,706	1,700
1993	1994	Fall	043350	11,152	11,139
1993	1994	Fall	043557	7,688	7,687
1993	1995	Spring	044213	3,228	3,227
		1993 Brood Year Total			**23,753**
1994	1995	Fall	043556	11,540	11,476
1994	1995	Fall	043558	11,654	11,645
1994	1995	Fall	043559	10,825	10,825
1994	1995	Fall	044231	6,324	6,260
1994	1996	Spring	044207	6,143	6,099
1994	1996	Spring	044208	1,362	1,357
		1994 Brood Year Total			**47,662**
1995	1996	Fall	044712	24,252	24,224
1995	1996	Fall	044236	11,202	11,200
1995	1996	Fall	044218	3,755	3,753
1995	1997	Spring	043829	12,521	12,517
		1995 Brood Year Total			**51,694**
1996	1997	Fall	044713	24,309	24,176
1996	1997	Fall	044714	22,996	22,583
1996	1997	Fall	044715	15,401	15,146
1996	1998	Spring	044646	11,193	11,134
1996	1998	Spring	044339	5,991	5,987
		1996 Brood Year Total			**79,026**
1997	1998	Fall	040139	22,389	22,366
1997	1998	Fall	040140	11,664	11,522
1997	1999	Spring	040144	7,954	7,948
		1997 Brood Year Total			**41,836**
1998	1999	Fall	040142	16,677	16,661
		1998 Brood Year Total			**16,661**

Appendix A2.–Detection of size-selectivity in sampling and its effects on estimation of size composition.

Results of hypothesis tests (K-S and χ^2 on lengths of fish MARKED during the first event and RECAPTURED during the second event	Results of hypothesis tests (K-S) on lengths of fish CAPTURED during the first event and CAPTURED during the second event
Case I:	
"Accept" H_O	"Accept" H_O
There is no size-selectivity during either sampling event.	
Case II:	
"Accept" H_O	Reject H_O
There is no size-selectivity during the second sampling event but there is during the first.	
Case III:	
Reject H_O	"Accept" H_O
There is size-selectivity during both sampling events.	
Case IV:	
Reject H_O	Reject H_O
There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

Case I: Calculate one unstratified abundance estimate, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of composition.

Case II: Calculate one unstratified abundance estimate, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data (p. 17).

Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Use lengths, ages, and sexes from only the second sampling event to estimate proportions in compositions, and apply formulae to correct for size bias to the data from the second event.

Whenever the results of the hypothesis tests indicate that there has been size-selective sampling (Case III or IV), there is still a chance that the bias in estimates of abundance from this phenomenon is negligible. Produce a second estimate of abundance by not stratifying the data as recommended above. If the two estimates (stratified and unbiased vs. biased and unstratified) are dissimilar, the bias is meaningful, the stratified estimate should be used, and data on compositions should be analyzed as described above for Cases III or IV. However, if the two estimates of abundance are similar, the bias is negligible in the UNSTRATIFIED estimate, and analysis can proceed as if there were no size-selective sampling during the second event (Cases I or II).

Appendix A3.–Numbers by sex and age for chinook salmon sampled on the Unuk River in 1999 by size group, location, and gear type. Age composition data are found in Table 3.

				BROOD YEAR AND AGE CLASS					
				1996	1995	1994	1993	1992	
				1.1	1.2	1.3	1.4	1.5	Total
PANEL A: SPAWNING GROUNDS SAMPLING BY SITE									
Spawning grounds Cripple Creek Event 2	Medium- and large-sized	Males	n	6	133	54	18	1	212
			%	2.8	62.7	25.5	8.5	0.5	62.0
		Females	n		2	53	74	1	130
			%		1.5	40.8	56.9	0.8	38.0
		Total	n	6	135	107	92	2	342
			%	1.8	39.5	31.3	26.9	0.6	100.0
Spawning grounds Gene's Lake Creek Event 2	Medium- and large-sized	Males	n	10	54	27	16		107
			%	9.3	50.5	25.2	15.0		67.7
		Females	n			24	27		51
			%			47.1	52.9		32.3
		Total	n	10	54	51	43		158
			%	6.3	34.2	32.3	27.2		100.0
Spawning grounds all other tributaries[a] Event 2	Medium- and large-sized	Males	n	27	421	228	104		780
			%	3.5	54.0	29.2	13.3		66.8
		Females	n		4	165	218		387
			%		1.0	42.6	56.3		33.2
		Total	n	27	425	393	322		1,167
			%	2.3	36.4	33.7	27.6		100.0
PANEL B: SPAWNING GROUNDS SAMPLING BY GEAR									
Spawning grounds Gear = rod and reel Event 2	Medium- and large-sized	Males	n	2	18	7	1		28
			%	7.1	64.3	25.0	3.6		80.0
		Females	n			4	3		7
			%			57.1	42.9		20.0
		Total	n	2	18	11	4		35
			%	5.7	51.4	31.4	11.4		100.0
Spawning grounds Gear = spear Event 2	Medium- and large-sized	Males	n	11	95	22	5		133
			%	8.3	71.4	16.5	3.8		67.2
		Females	n			25	39	1	65
			%			38.5	60.0	1.5	32.8
		Total	n	11	95	47	44	1	198
			%	5.6	48.0	23.7	22.2	0.5	100.0
Spawning grounds Gear = net Event 2	Medium- and large-sized	Males	n		8	15	2	1	26
			%		30.8	57.7	7.7	3.8	70.3
		Females	n			4	7		11
			%			36.4	63.6		29.7
		Total	n		8	19	9	1	37
			%		21.6	51.4	24.3	2.7	100.0
Spawning grounds Gear = snag Event 2	Medium- and large-sized	Males	n	8	111	77	45		241
			%	3.3	46.1	32.0	18.7		67.9
		Females	n		2	50	62		114
			%		1.8	43.9	54.4		32.1
		Total	n	8	113	127	107		355
			%	2.3	31.8	35.8	30.1		100.0
Spawning grounds Gear = carcass pickup Event 2	Medium- and large-sized	Males	n	3	17	8	3		31
			%	9.7	54.8	25.8	9.7		39.7
		Females	n		1	21	25		47
			%		2.1	44.7	53.2		60.3
		Total	n	3	18	29	28		78
			%	3.8	23.1	37.2	35.9		100.0

-continued-

Appendix A3.–(Page 2 of 2).

				BROOD YEAR AND AGE CLASS					
				1996	1995	1994	1993	1992	
				1.1	1.2	1.3	1.4	1.5	Total
PANEL C: ALL TRIBUTARIES COMBINED									
Spawning grounds Event 2	Medium-sized	Males	n	24	201	1			226
			%	10.6	88.9	0.4			99.6
		Females	n				1		1
			%				100.0		0.4
		Total	n	24	201	1	1		227
			%	10.6	88.5	0.4	0.4		100.0
Spawning grounds Event 2	Large-sized	Males	n		48	128	56	1	233
			%		20.6	26.9	11.8	0.2	48.9
		Females	n		3	104	135	1	243
			%		1.2	42.8	55.6	0.4	51.1
		Total	n		51	232	191	2	476
			%		10.7	48.7	40.1	0.4	100.0
Spawning grounds Event 2	Medium- and large-sized	Males	n	24	249	129	56	1	459
			%	5.2	54.2	18.3	8.0	0.1	65.3
		Females	n		3	104	136	1	244
			%		1.2	42.6	55.7	0.4	34.7
		Total	n	24	252	233	192	2	703
			%	3.4	35.8	33.1	27.3	0.3	100.0
PANEL D: LOWER UNUK RIVER GILLNET SAMPLES									
Lower Unuk River gillnet samples Event 1	Medium-sized	Males	n	3	118	1			122
			%	2.5	96.7	0.8	0.0		99.2
		Females	n				1		1
			%				0.8		0.8
		Total	n	3	118	1	1		123
			%	2.4	95.9	0.8	0.8		100.0
Lower Unuk River gillnet samples Event 1	Large-sized	Males	n		60	98	48		206
			%		29.1	28.0	13.7		58.9
		Females	n		1	62	81		144
			%		0.7	43.1	56.3		41.1
		Total	n		61	160	129		350
			%		17.4	45.7	36.9		100.0
Lower Unuk River gillnet samples Event 1	Medium- and large-sized	Males	n	3	178	99	48		328
			%	0.9	54.3	30.2	14.6		69.3
		Females	n		1	62	82		145
			%		0.7	42.8	56.6		30.7
		Total	n	3	179	161	130		473
			%	0.6	37.8	34.0	27.5		100.0

[a] Includes Boundary, Chum, Clear, Kerr, and Lake creeks, the Eulachon River, and the Unuk River mainstem, combined.

Appendix A4.–Numbers of adult Unuk River chinook salmon examined for adipose finclips, sacrificed for CWT sampling purposes, and the total valid coded-wire tags decoded, 1992 brood year to present.

PANEL A. NUMBERS OF ADULT CHINOOK SALMON AND AD-CLIPPED FISH SAMPLED AND THE ASSOCIATED MARKED FRACTION OBTAINED FOR EACH BROOD YEAR

Brood year	Age class	Year sampled	Number examined	Adipose clips	Number sacrificed	Number of valid tags: Fall	Spring	Total	% Valid	Percent Adipose	Marked fraction (θ): % Valid	Event
1992	1.2	1996	33									1+2
1992	1.3	1997	162	7	7	6	1	7	100.0	4.3	4.3	1
1992	1.3	1997	324	7	7	4		4	57.1	2.2	1.2	2
1992	1.4	1998	139	6	6	2	2	4	66.7	4.3	2.9	1
1992	1.4	1998	206	10	5	2	2	4	80.0	4.9	3.9	2
1992	1.5	1999	1									2
1992 Brood Year Total			865	30	25	14	5	19	76.0	3.5	2.6	
1993	1.1	1996	4	1	1	1		1	100.0	25.0	25.0	2
1993	1.2	1997	106	9	9	8	1	9	100.0	8.5	8.5	1
1993	1.2	1997	211	23	23	20	2	22	95.7	10.9	10.4	2
1993	1.3	1998	350	31	31	24	4	28	90.3	8.9	8.0	1
1993	1.3	1998	443	33	16	11	4	15	93.8	7.4	7.0	2
1993	1.4	1999	130	8						6.2		1
1993	1.4	1999	173	24	16	12	3	15	93.8	13.9	13.0	2
1993 Brood Year Total			1,417	129	96	76	14	90	93.8	9.1	8.5	
1994	1.1	1997	56	4	4	2	2	4	100.0	7.1	7.1	2
1994	1.2	1998	105	10	9	4	5	9	100.0	9.5	9.5	1
1994	1.2	1998	225	20	18	10	6	16	88.9	8.9	7.9	2
1994	1.3	1999	161	18	2	1		1	50.0	11.2	5.6	1
1994	1.3	1999	211	25	11	4	5	9	81.8	11.8	9.7	2
1994 Brood Year Total			758	77	44	21	18	39	88.6	10.2	9.0	
1995	1.1	1998	8	1	1	1		1	100.0	12.5	12.5	1
1995	1.1	1998	67	14	13	7	5	12	9239	20.9	19.3	2
1995	1.2	1999	179	21	20	15	5	20	100.0	11.7	11.7	1
1995	1.2	1999	239	33	26	15	11	26	100.0	13.8	13.8	2
1995 Brood Year Total			493	70	61	38	22	60	98.4	14.2	14.0	
1996	1.1	1999	53	6	6	4	1	5	83.3	11.3	9.4	2
1996 Brood Year Total			53	6	6	4	1	5	83.3	11.3	9.4	

Appendix A5.–Computer files used to estimate the spawning abundance of chinook salmon in the Unuk River in 1999.

File name	Description
99unk41.xls	Spreadsheet containing all the mark-recapture data with various pivot table results, Tables 1 - 6, Figures 5 and 8, Appendices A1, A3, and A4, abundance estimates, SPAS results, bootstrap results, and chi-squared analyses.
99unk41ks.xls	Spreadsheet containing the Kolmogorov-Smirnov (K-S) 2-sample test results and various figures and data sets used in these calculations. Figures 6 and 7 used in 99unk41a.doc are also included.
BootVar.bas	QBASIC program used for bootstrapping abundance estimates to estimate variance and bias.
99unk41lg.dat	Data file for large chinook salmon for BootVar.exe.
99unk41md.dat	Data file for medium chinook salmon for BootVar.exe.
99unk41lg.out	Output from BootVar.bas on large chinook salmon.
99unk41md.out	Output from BootVar.bas on medium chinook salmon.
SPAS.exe	Stratified Population Analysis System (SPAS) lets the user perform computer analysis of 2-sample mark-recovery data where each sample is from a geographically or temporally stratified population.
99spas41lg.dat	Data file containing the data on large chinook salmon used in SPAS.exe.
99spas41md.dat	Data file containing the data on medium chinook salmon used in SPAS.exe.
99spas41lg.out	Output from SPAS.exe on large chinook salmon.
99spas41md.out	Output from SPAS.exe on medium chinook salmon.